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ARL Human Factors Engineering Technology: Overview of 6.2 Efforts for Dr. Lemnios, DDRE

by Scott Kerick, Michael LaFiandra, Donald Headley, John Lockett, Susan Hill, Charneta Samms, Mary Binseel, and Kaleb McDowell

ARL-TR-5956 **March 2012**

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14. ABSTRACT

The research programs summarized in this report describe efforts proposed by scientists and engineers in the U.S. Army Research Laboratory's (ARL) Human Research and Engineering Directorate that support further understanding of Soldier performance and the interactions between Soldiers and technologies. This report focuses on the 6.2 funding for the Soldier performance and Soldier-machine interaction research funded under the R2A designator PE62716AH70 (Human Factors Engineering) and comprises four areas of research: (1) Information Processing for Collaboration and Decision Making, (2) Human Performance Modeling/Improved Man-Machine Interfaces, (3) Human-Robotic Interaction, and (4) Soldier-focused Neurotechnologies. Summaries for each area include a brief description of the research, types of experiments, tests, and demonstrations employed, methods employed, value of simulation space versus real space, and collaborations and related work.

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1. Introduction

Although U.S. military power is presently unmatched in terms of its war technology and materiel (i.e., technologically superior ground vehicles, fighter jets, and warships, etc.), its most critical assets are the men and women who voluntarily serve to protect the Nation's interests. The U.S. Army considers the Soldier central to mission success and, accordingly, has recently emphasized the importance of better understanding moral, cognitive, and physical aspects of Soldier performance across a full spectrum of operations (Training and Doctrine Command [TRADOC], 2008).[1] This emphasis has evolved from the increasingly complex and diverse operating environments in which Soldiers perform, and the increased demands and stresses that are unique to current conflict (e.g., small-unit conflicts and asymmetrical warfare). Furthermore, due to these increasing complexities coupled with rapid technological advancements, the development of the very technologies aimed at supporting the Army mission without the consideration and understanding of the capabilities of our Soldiers will ultimately limit the effectiveness of *both* the technologies and our Soldiers.

The mission of the U.S. Army Research Laboratory (ARL) Human Research & Engineering Directorate (HRED) is to conduct a broad-based program of scientific research and technology development directed toward optimizing Soldier performance, Soldier-machine interactions, and training technology effectiveness across the military environment. ARL HRED provides the Army and ARL with human factors leadership to ensure that Soldier performance requirements are adequately considered in technology development and system design and transitions results and products to the broad collaborator and customer base—to academia, the Research, Development, and Engineering Centers, other government agencies, industry, and Program Managers. ARL bins this work into two Major Laboratory Programs: (1) Human Dimension and (2) Simulation and Training Technology. The Assistant Secretary of the Army for Acquisition, Logistics, and Technology (ASAALT) bins this research into the Soldier (Non-Medical) Portfolio, Human Dimension Sub-Portfolio, with Investment Areas of Training Tools and Human Systems Integration. This research is also applied against the Assistant Secretary of Defense for Research and Engineering (ASD(R&E)) Human Systems Priority, both Training for Readiness and Interfaces.

All Soldier Portfolio tasks funded at $3M or greater were briefed as a part of the recent review to ASD(R&E) in September 2011; however, because of the breadth of the research, a follow-on information paper was requested. This report focuses on the 6.2 funding for the Soldier performance and Soldier-machine interaction research funded under the R2A designator PE62716AH70 (Human Factors Engineering). This is the work that constitutes ARL's Human

[1]TRADOC Pamphlet 525-3-7-01. The U.S. Study of the Human Dimension in the Future 2015–2024. http://www.tradoc.army.mil/tpubs/pams/p525-3-7-01.pdf (accessed 2008).

Dimension; ASAALT's (Non-Medical), Human Dimension, Human Systems Integration Investment; and the Human Systems (HS) Priority Steering Council's (PSC) Interfaces priority. (Note: There are associated 6.1 programs that serve as the on-ramp to this work. Also, the simulation and training technology 6.1–6.3 research is funded through separate lines.)

As briefed, this research area comprises four task areas:

1. Information Processing for Collaboration and Decision Making
2. Human Performance Modeling/Improved Man-Machine Interfaces
3. Human-Robotic Interaction
4. Soldier-focused Neurotechnologies

In the research summaries, the questions posed during the review are addressed:

- What types of experiments/studies/tests/demonstrations are employed?
- What types of methods are used?
- What is value of simulation space versus real space within this research?
- What are the end products/artifacts/results/findings?
- Can you comment on related work performed elsewhere?

The details are different for each research area; however, with respect to types of experiments /studies/tests/demonstrations and methodological approaches, human systems research draws most heavily on experimental psychology. In this approach, laboratory settings are used to investigate human subject behavior as a function of tightly controlled parameters without extraneous influences. While this approach is the foundation, it is only part of a larger research framework that employs a range of methods from predictive computational representations of human cognition and behavior to focus research and serve as a receptacle for research results to naturalistic observation of human behavior in militarily relevant field environments and military exercises. Human systems research uses a range of scaled simulations and virtual environments in a step-wise progression from lab to field to approximate battlefield stressors in controlled settings. Indeed the nature and value of simulation versus real space is a subject of research itself. For example, to what degree is visual fidelity the defining factor of simulation realism as compared with auditory or tactile fidelity?

The end products or "artifacts" of human sciences research likewise cover a range. Reports of research results are published in Army formats, logged into the Defense Technical Information Center (DTIC), presented at workshops and scientific conferences, and in peer-reviewed journals. From a body of research, generalizable guidelines and recommendations for system interface design are derived and transitioned via the open literature, to military developers in the government and industry, and to the Soldier community as they apply to system training and the

development of tactics, techniques, and procedures for system employment. Working with the engineering community, the end products include prototype systems, novel interfaces, and software algorithms that result in a better match of human and system capabilities, and ultimately, improve human-system performance.

Each of these areas is coordinated with research throughout Department of Defense (DoD) through numerous mechanisms such as the ASD(R&E) Human Systems Community of Interest, a formal Annual Performance Plan, and stakeholders meetings with the customers, transition partners, and collaborators. The scientific foundation of the work is assessed through those same venues and also through formal reviews by the National Academies of Science and the peer-review process in the open literature and scientific conferences in the U.S. and internationally. ARL HRED holds formal Memoranda of Agreement with other Army agencies and with other service laboratories to include the Air Force Research Laboratory (AFRL) and the Office of Naval Research (ONR). ARL HRED is an annual sponsor of the ASD(R&E)-endorsed DoD Human Factors Engineering Technical Advisory Group that has met twice a year for more than 30 years and serves as a working-level venue for research exchange and networking. All of these steps insure that the ARL HRED program is unique and is taking approaches to critical research issues that are relevant to the military, while at the same time leveraging research and technological developments that are made at other agencies throughout the DoD, other government agencies, and in academia and industry.

2. Research Areas

2.1 Information Processing for Collaboration and Decision Making

The *Information Processing for Collaboration and Decision Making* research program investigates how communication and information networks influence and are influenced by human behavior in the context of military decision making. There is a need to understand what aspects of network operations cause an undue cognitive burden to commanders and dismounted Soldiers who are getting information from media such as radios, text messages, e-mails, sensors, and ground and air unmanned assets. Studies investigate the effects of technology on cognitive workload, information flow, team collaboration, organizational effectiveness, situation awareness, and decision making. By understanding the effects of network parameters on the ability to perform effective mission command, small team, and dismounted Soldier interaction in a networked environment, we will be able to help align Soldier and system capabilities in real time to support decision making, guide the design of human-team-system interaction, and develop decision aids to manage information by users who must rapidly and efficiently process information from sources at multiple levels. Our efforts contribute to the Data to Decisions initiative.

Two key collaborative efforts are underway to study the effects of distributed collaboration on performance in complex, dynamic network-enabled operations using cognitive, computer, and social network sciences. The Tactical Human Integration of Networked Knowledge (THINK) Army Technology Objective (ATO) is performing research that will help shape proper reliance on networked information technology by deriving methods and tools to train, improve, and assess information sharing and collaboration in network-enabled operations to support decision making in data/information rich environments. Our research environments range from computational modeling, to networked simulations in a laboratory environment, to large-scale simulated exercises. Fiscal year 2012 (FY12) experiments will culminate in a workshop/demonstration in which lessons learned are transitioned to stakeholders (e.g., TRADOC's Mission Command Battle Lab at Fort Leavenworth, KS) to inform the creation of command and control data repositories, information products, applications, and services that support the Soldier's workflow. These items will also transition to the second main research venue, the ARL-led Warrior's Lens component of the Research and Demonstration Project led by the Communications and Electronics Research, Development, and Engineering Center's (CERDEC) Integrated Decision Enhancing Capabilities in Dynamic Environments (I-DECIDE). It will develop information processing technologies that enable Company Intelligence Support Team (COIST) analysts to collect, manage, and exploit widely disparate information for situation awareness. Research will focus on the goals, tasks, and data requirements of the COIST analyst, and will involve studies in cognitive analysis and workflow. The near-term transitions will be to ASAALT's Mission Command Technology Enabled Capabilities Demonstration (TECED) and will culminate in evaluations and joint demonstrations with ARL and CERDEC.

Because of the interdisciplinary nature of the network science initiative and to address the longer-term research questions, ARL HRED is partnering with ARL's Computational Information Sciences Directorate (CISD), CERDEC, and the Army Research Institute for Behavior and Social Sciences (ARI). We are also aligned and working with the Network Science Collaborative Technology Alliance of academic and industry partners, the Mission Command Battle Lab, the United States Military Academy (USMA) Network Science Center, and the Human Interface to Networks section of the Human Systems Priority and Community of Interest (CoI).

2.2 Human Performance Modeling and Improved Man-machine Interfaces

First, the *Human Performance Modeling* program is focused on developing and enhancing human performance modeling tools that enable early, cost-effective insertion of Manpower and Personnel Integration (MANPRINT), the Army's programmatic implementation of Human Systems Integration (HSI) criteria into pre-milestone A acquisition requirements to optimize Soldier-system performance and cost. By using predictive and diagnostic human performance modeling tools early in the acquisition process, potential performance problems can be identified and resolved sooner resulting in better designed systems. The development of HSI tools and analysis techniques requires the use of empirical human performance data and greater

understanding and integration of models, methods, and techniques from other fields (e.g., economics, survivability, logistics, computer science, material science, medical, and organizational psychology). Integrated and quantitative consideration of design tradeoffs across MANPRINT domains such as human engineering, manpower, personnel, training, safety, Soldier survivability, and health hazard assessment is also required. Along with tool development, this program also promotes the use of MANPRINT techniques, tools, and technologies through training, technical support, marketing, and usability enhancement.

Work in this area involves development of predictive models and design tradeoff analysis tools informed by empirical human performance data. Where possible, existing tools are leveraged and enhanced. This includes the ARL-developed Improved Performance Research Integration Tool (IMPRINT). IMPRINT uses discrete event, stochastic simulation for early, cost-effective inclusion of MANPRINT criteria into the system development process. Analyses typically involve system design tradeoffs considering human performance; operator roles; cognitive workload; manpower; training, tactics and procedures (TTPs); and automation level. Two major enhancements are underway for IMPRINT. One will enable consideration of different system types within the same maintenance manpower analysis to more accurately predict man-hours associated with maintaining multiple systems. The second enhancement will improve the fidelity with which human response to environmental stressors that affect task and mission performance are modeled.

Human Performance Modeling also includes models of the physical characteristics of the Soldier population such as human figure models for workspace accommodation analysis and tradeoff analysis tools to assess protection level versus load versus survivability for dismounted Soldiers. Near term, a series of field and laboratory experiments will be conducted on the effects of ballistic armor coverage on Soldier mobility and performance. Data from the studies will be used to improve ARL gait biomechanics models and ARL's Survivability and Lethality Analysis Directorate's (SLAD) survivability analysis tools.

The development of tools and models is fed by empirical data from basic human performance research conducted by ARL, DoD, and academia. Because IMPRINT is distributed to other government agencies, U.S. private industries with U.S. government contracts, and U.S. colleges and universities working in HSI, it serves as a transition mechanism for research via the development of algorithms and models. AFRL has contributed algorithms on training performance differences and the N1 sponsored development of sea state algorithms. The ONR Performance Shaping Functions (PSF) program will be translating their research results into algorithms developed for inclusion into IMPRINT. ARL HRED will work with other ARL Directorates (SLAD and the Weapons and Materials Research Directorate [WMRD]) to develop an understanding of the tradeoffs among area of coverage of ballistic armor, Soldier performance and mobility, and survivability. Human figure model development is coordinated with Natick Soldier RDEC (NSRDEC) anthropometric data collection and analysis. The analytical techniques, tools, and models developed by ARL are shared across the DoD and more generally

the HSI community, making ARL a leader in the human performance modeling area. This research area is supported by a technology planning annex (TPA) with the Army G1 MANPRINT Office for development of HSI tools and analysis techniques.

Second, the *Improved Man-Machine Interfaces* research area is motivated by the fact that technology designed to enhance Soldier performance often imposes both physical and cognitive stress on the Soldier in ways that equipment developers do not envision. This research area addresses optimization of the way Soldiers use emerging technology by providing system designers with the knowledge and tools necessary to design equipment that does not enhance one aspect of performance while sacrificing another aspect that is critical to overall mission success. Specifically, this research area focuses on understanding the interaction between physical and cognitive stress and their effect on individual dismounted Soldier and small team performance, and additionally understanding the value of using alternative technologies, such as bone conduction communications and tactile displays, for providing information to the Soldier.

A mix of laboratory, simulation, and field experiments are used to determine the effects of Soldier equipment (load carriage devices, helmets, weapon sights, information systems, tactile systems, etc.) on performance. New approaches to measure human-system performance that are both operationally relevant and minimally invasive are being developed. In order to collect data in operationally relevant environments while still allowing for a high level of experimental control, ARL HRED has developed unique, state-of-the-art simulated operational environments.

One research environment, SPEAR, is used to investigate the effects Soldiers carrying operationally realistic loads while performing a mission-based scenario, such as movement to contact, which requires both movements through a wooded or urban environment and the integration of information provided via a Wi-Fi network. Studies on the ability of Soldiers to perceive auditory and multimodal information are conducted in the Environment for Auditory Research (EAR), a multi-laboratory indoor/outdoor facility that produces a militarily relevant sound spectrum in a highly controlled and repeatable process. In the near term, methods and guidelines for optimizing Soldier performance by minimizing detrimental effects of new Soldier equipment on Soldier performance will be transitioned to the Soldier equipment development communities at NSRDEC, CERDEC, etc. Additionally, guidelines for using alternative communication modalities (bone conduction and tactile) will be transitioned to NSRDEC. The far-term focus will be on small teams and specifically established metrics and guidelines describing how to effectively distribute physical and cognitive load within the small team to optimize mission performance. The results of these efforts will be novel, operationally relevant metrics, equipment design software tools, and design guidelines that will be transitioned to dismounted Soldier equipment and system developers.

Physical and cognitive stressors have typically been studied in isolation of each other. In contrast, this effort is studying the interaction of physical and cognitive stress on Soldier performance with an aim toward understanding the effect of equipment on the Soldier's ability to

perceive their environment. The effort leverages the High-Definition Cognition Army Technology Objective, Soldier and Small Unit Load Management Program at NSRDEC, ARL's Cognition & Neuroergonomics (CAN) Collaborative Technology Alliance (CTA), ARL's Network Science CTA, the proposed Blast and Ballistic Protection Program, and the Marine Corps Load Effects Assessment Program.

2.3 Human-Robotic Interaction

The *Human-Robotic Interaction* research program is driven by the vision that Future Soldiers will supervise and interact with multiple semi-autonomous unmanned vehicles (UVs) in urban and other environments. ARL HRED's Human-Robotic Interaction efforts are directed at identifying human-centered interface design knowledge that will improve Soldiers' performance with UVs, and improve manned/unmanned interactions by teaming concepts through a better understanding of supervisory control strategies. We evaluate Soldier monitoring technologies (such as eye tracking or physiological measures) within crew station design concepts to enable adaptive automation as a means to compensate for Soldier degraded performance (such as fatigue or cognitive overload). The effort will improve Soldier and mission performance by reducing cognitive burden, increasing situation awareness, and enabling effective teaming of Soldiers and unmanned systems.

In the near term, a series of small experiments and evaluations are being conducted to identify and refine design concepts that will culminate in a final combined capstone experiment in FY12 for two current ATOs. Research will continue to examine the impact of technologies and human-centered concepts (e.g., stereovision, haptic feedback from controls, voice commands for robots, and decision aids for managing multiple control/supervision tasks) that will minimize cognitive burden and enhance Soldier-robot team communication, collaboration, and cognitive compatibility; results will be evaluated in a capstone experiment in FY16. The numerous small experiments may use simulation of ground and air UVs in controlled, repeatable environments. Simulation may also be used to evaluate concepts and technology that do not yet exist. Other experiments and capstones will seek to evaluate UV concepts and strategies in realistic venues with actual technology to examine performance in field-like, less-controlled environments. Near-term products and transitions include design guidelines on human-robot teaming principles (e.g., operator TTPs) and control interfaces for reliable and safe robotics operation in complex urban terrain, where robots may be in close proximity to people and other vehicles. We will provide design guidance on how to effectively provide Soldiers with visual local situation awareness and how to conduct safe maneuvering with indirect vision technology. Far term, we will provide (1) design guidance on communications methods to enable bilateral and cooperative task execution with UVs, (2) human-centered inputs to autonomous intelligence algorithms for shared mental and world models, and (3) design guidance on implementing algorithms for robot awareness of society and culture.

ARL HRED is performing research in effective Soldier-robot teaming, particularly with ground robots interacting in close proximity to Soldiers. Collaborations have been established with academia (George Mason University, Brigham Young University, Ben Gurion University [Israel]) and other government agencies (Tank and Automotive RDEC [TARDEC], Aviation and Missile RDEC [AMRDEC], Navy Space Warfare [SPAWAR], and AFRL). We leverage our collaboration with ARL's Robotics CTA and its industry and academic partners (General Dynamics Robotics Systems, Boston Dynamics, California Institute of Technology Jet Propulsion Lab, Carnegie Mellon, Florida A&M, QinetiQ North America, University of Central Florida, University of Pennsylvania, iRobot, MIT.) ARL is coordinating research in DoD through the DoD Human Systems Community of Interest, for example, through the DoD Human Systems CoI Human-Centered Autonomy Workshop (held September 2011 at AFRL), as well as interactions at the researcher level.

2.4 Soldier-focused Neurotechnologies

The *Soldier-focused Neurotechnologies* research program aims to enhance Soldier-system performance by developing brain-computer neurotechnologies that use cognitive state modeling, and assess and validate emerging proof-of-principle neurotechnologies with a near-term focus on subsystems that predict mounted and dismounted Soldier performance and improve Soldier-system communications. This program will leverage state-of-the-art neurotechnologies, novel research paradigms, advanced signal processing, statistical analysis, and modeling tools to enable the far-term goals of making wide-ranging improvements in effectiveness across systems influenced by lapses in Soldier performance and in Soldier-system and Soldier-Soldier communications across a broad spectrum of Army autonomy and network applications.

A series of experiments and developmental efforts are envisioned to yield two sub-systems. The first sub-system will be a wearable device that, once calibrated to the individual Soldier, will be able to predict moment-to-moment Soldier performance and provide that information to other Soldiers and vehicle-based systems. Simulation will be used for cost-effective development of this performance monitoring system, but validation will occur by monitoring Soldiers performing real-world mobility, robotic control, scanning, and other vigilance tasks and comparing predicted performance to actual performance. The second system will be a neuroscience laboratory-based device that enables the development of a joint human-computer semantic lexicon to communicate objects of interest in an environment for rapid repurposing of robotic assets. The developed lexicon can be transitioned into systems to improve the ability of the computer to interpret Soldier intent. Final experimentation will examine Soldier-robot mission effectiveness when the joint human-computer lexicon is incorporated versus not incorporated in robotic control and remote sensing aspects of the Soldier-system interface.

ARL HRED is performing unique research in advancing the research and development of brain-computer interaction technologies designed to enhance Soldier-system performance and communications. Collaborations for this line have been established with industry (DCS, SAIC, Neuromatters), academia (Columbia University, University of California at San Diego, National Chao Tung University), and other government agencies (TARDEC, NSRDEC, AFRL, Navy Research Laboratory [NRL], and the Federal Aviation Administration [FAA]) through independent contracts, collaborative agreements, and the CAN CTA.

3. Conclusion

The research programs summarized in this report describe efforts proposed by scientists and engineers in ARL's Human Research and Engineering Directorate that support further understanding of Soldier performance and the interactions between Soldiers and technologies. In particular, the Improved Equipment Design for the Dismounted Soldier research program will leverage investigations of the interaction between cognitive and physical demands in both individual Soldiers and small units to improve equipment design and enhance Soldier and unit performance. The Information Processing for Collaboration and Decision Making research program will advance our understanding of the effects of network technology on cognitive workload, team collaboration, organizational effectiveness, situation awareness, and decision making. The Human Performance Modeling research program will further advance the development and enhancement of human performance modeling tools, which has implications for the design of enhanced Soldier systems and a more efficient acquisition process by identifying potential performance problems resulting in better designed systems. The Human-Robotic Interaction research will improve Soldier-robot interactions and team performance through better understanding of supervisory control strategies and providing guidelines for efficient interface designs. The Soldier-focused Neurotechnologies research program will advance the development of proof-of-concept information systems to function in a manner that is more natural and intuitive to humans, adaptive to the human's needs and intentions in a timely manner, and helpful for mitigating Soldier-system performance in complex dynamic environments characteristic of current and future conflicts.

List of Symbols, Abbreviations, and Acronyms

AFRL	Air Force Research Laboratory
AMRDEC	Aviation and Missile RDEC
ARI	Army Research Institute
ARL	U.S. Army Research Laboratory
ASAALT	Assistant Secretary of the Army for Acquisition, Logistics, and Technology
ASD(R&E)	Assistant Secretary of Defense for Research and Engineering
ATO	Army Technology Objective
CAN	Cognition & Neuroergonomics
CERDEC	Communications and Electronics Research, Development, and Engineering Center
CISD	Computational Information Sciences Directorate
CoI	Community of Interest
COIST	Company Intelligence Support Team
CTA	Collaborative Technology Alliance
DoD	Department of Defense
DTIC	Defense Technical Information Center
EAR	Environment for Auditory Research
FAA	Federal Aviation Administration
HSI	Human Systems Integration
HRED	Human Research & Engineering Directorate
HS	Human Systems
I-DECIDE	Integrated Decision Enhancing Capabilities in Dynamic Environments
IMPRINT	Improved Performance Research Integration Tool
MANPRINT	Manpower and Personnel Integration
NRL	Navy Research Laboratory

NSRDEC	Natick Soldier RDEC
ONR	Office of Naval Research
ONR PSF	ONR Performance Shaping Functions
PSC	Priority Steering Council
SLAD	Survivability and Lethality Analysis Directorate
SPAWAR	Space Warfare
TARDEC	Tank and Automotive RDEC
TECED	Technology Enabled Capabilities Demonstration
THINK	Tactical Human Integration of Networked Knowledge
TPA	technology planning annex
TRADOC	Training and Doctrine Command
TTPs	training, tactics and procedures
USMA	United States Military Academy
UVs	unmanned vehicles
WMRD	Weapons and Materials Research Directorate

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